# Search for Supersymmetry

## Search for electroweak production of supersymmetric states in Non-Universal Higgs Mass model with two extra parameters compressed scenario with the ATLAS detector

Yu-Ting Shen

Department of Physics and Astronomy
The University of Oklahoma

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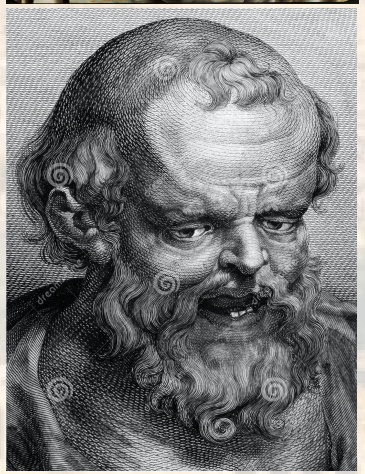
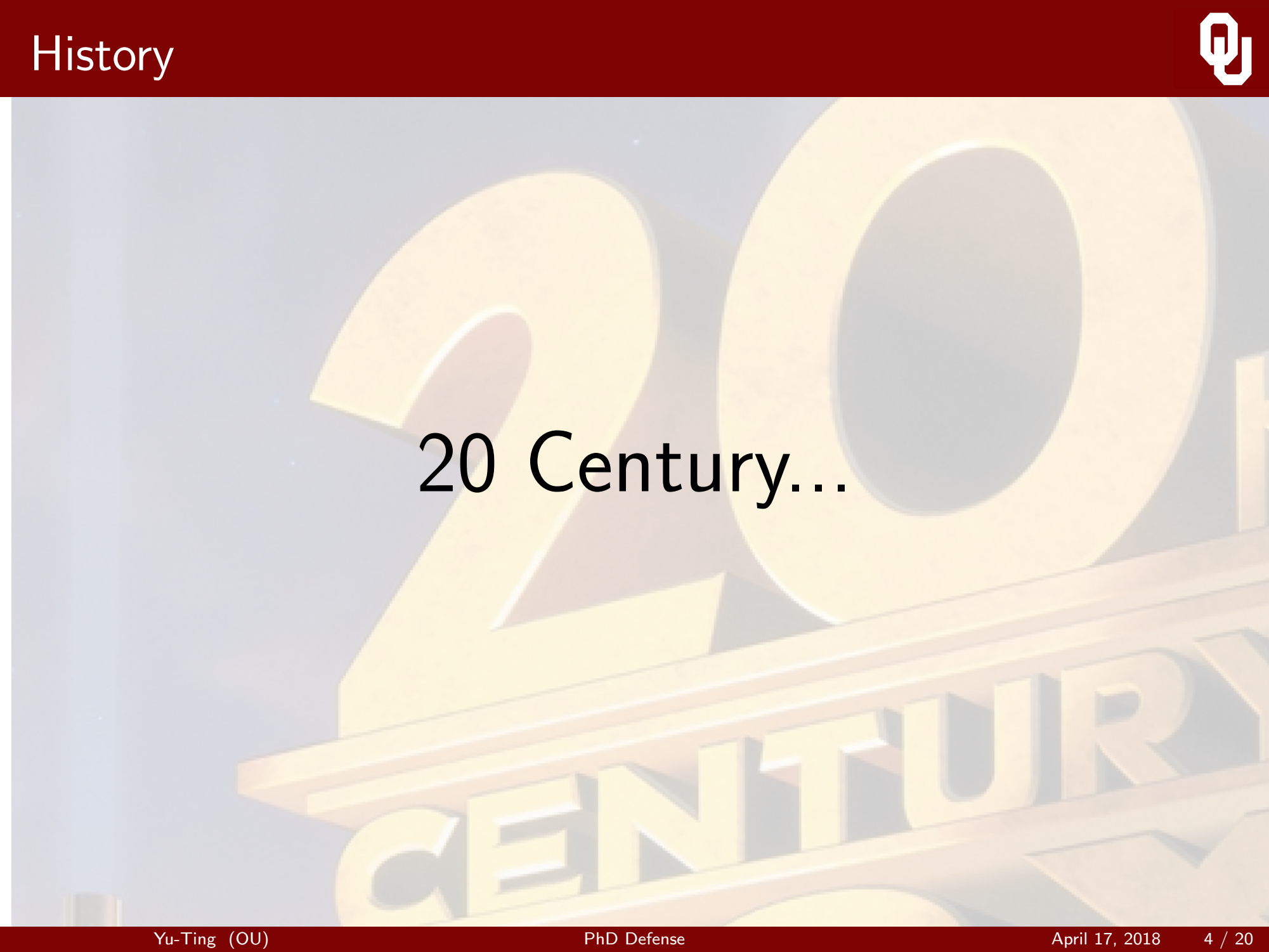
# Ancient Greece...

# History

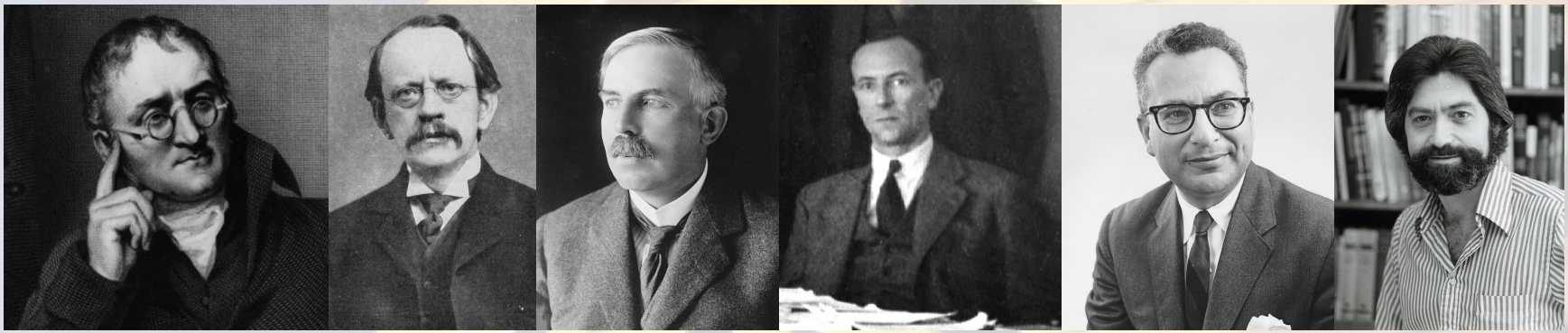
- Aristotle:
  - All materials on Earth were made of the four elements: Earth, Fire, Water, and Air
  - All substances were made of small amounts of these four elements of matter
- 460 - 370 B.C. Democritus:
  - All matter consists of invisible particles called atoms
  - Atoms are indestructible
  - Atoms are solid but invisible
  - Atoms are homogenous
  - Atoms differ in size, shape, mass, position, and arrangement
    - ⋆ Solids are made of small, pointy atoms
    - ⋆ Liquids are made of large, round atoms
    - ⋆ Oils are made of very fine, small atoms that can easily slip past each other




20 Century...

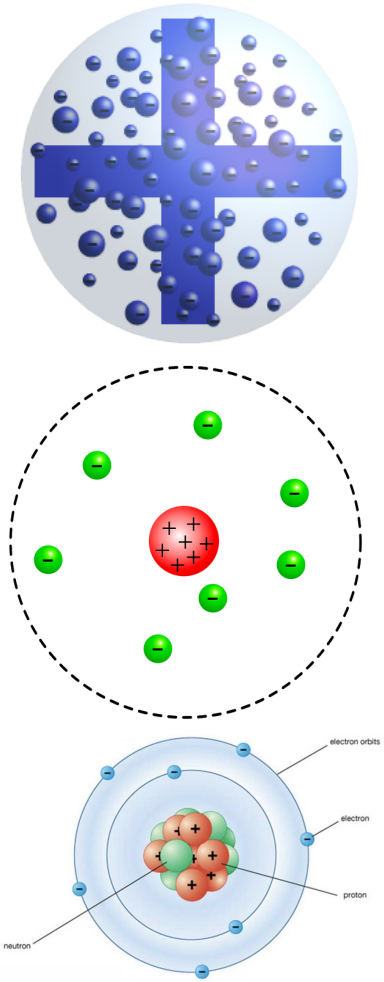
# History

- 1803 John Dalton:
  - Elements are made of extremely small particles called atoms
  - Atoms cannot be subdivided, created or destroyed
- J.J Thomson discovered electrons and proposed the Plum pudding model in 1904
- Rutherford discovered subatomic structure in 1909: nucleus
- Chadwick discovered the neutron in 1932
- Gell-Mann and Zweig proposed quark model in 1964 and quarks were observed in 1968.



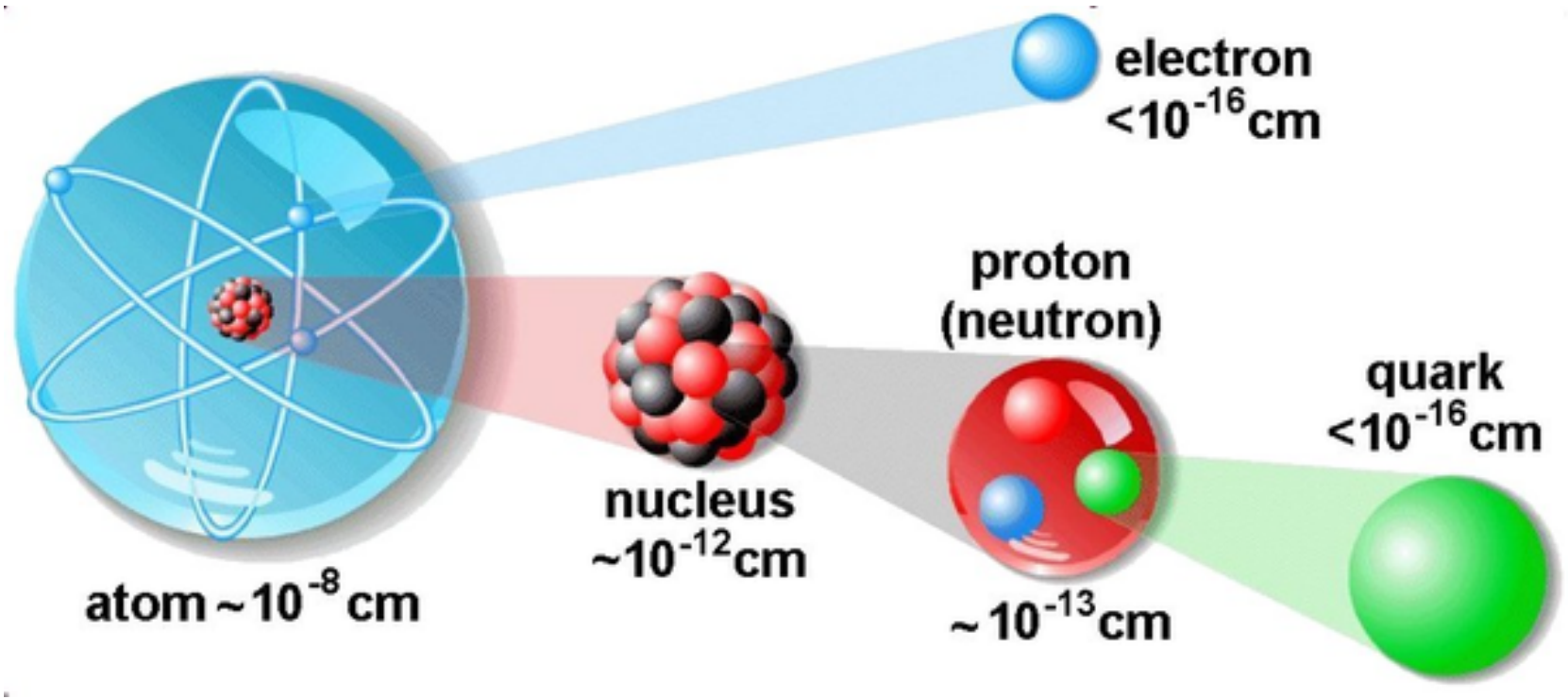
# History

- Plum pudding model
  - Proposed by J.J Thomson
  - Atoms are electrically neutral $\Rightarrow$ There must be a positive charge as well.
  - An atom is consisted of negative electrons randomly scattered within a sphere of positive charge.
- Rutherford model
  - Proposed by Rutherford based on the experimental results.
  - An atom is made up of a central charge (atomic nucleus) surrounded by a cloud of (presumably) orbiting electrons. I
  - Nucleus is a very small volumn in comparison to the rest of the atom. A relatively high central charge concentrated in nucleus and it also contains the bulk of the atomic mass of the atom.
- Bohr model
  - Proposed by Bohr
  - The atom is a small, positively charged nucleus surrounded by electrons that travel in circular orbits around the nucleus
  - It is similar to structure of the Solar System.



# History

- The atomic structure we know now:

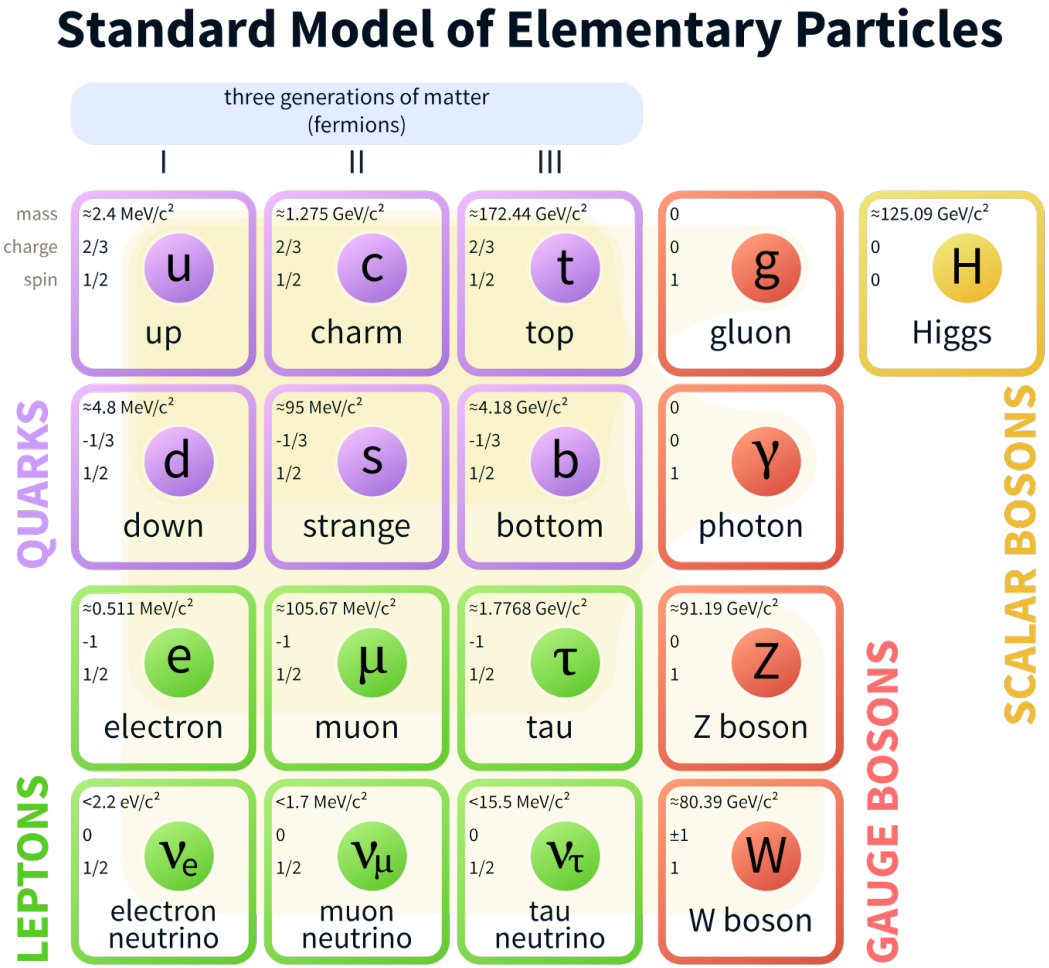


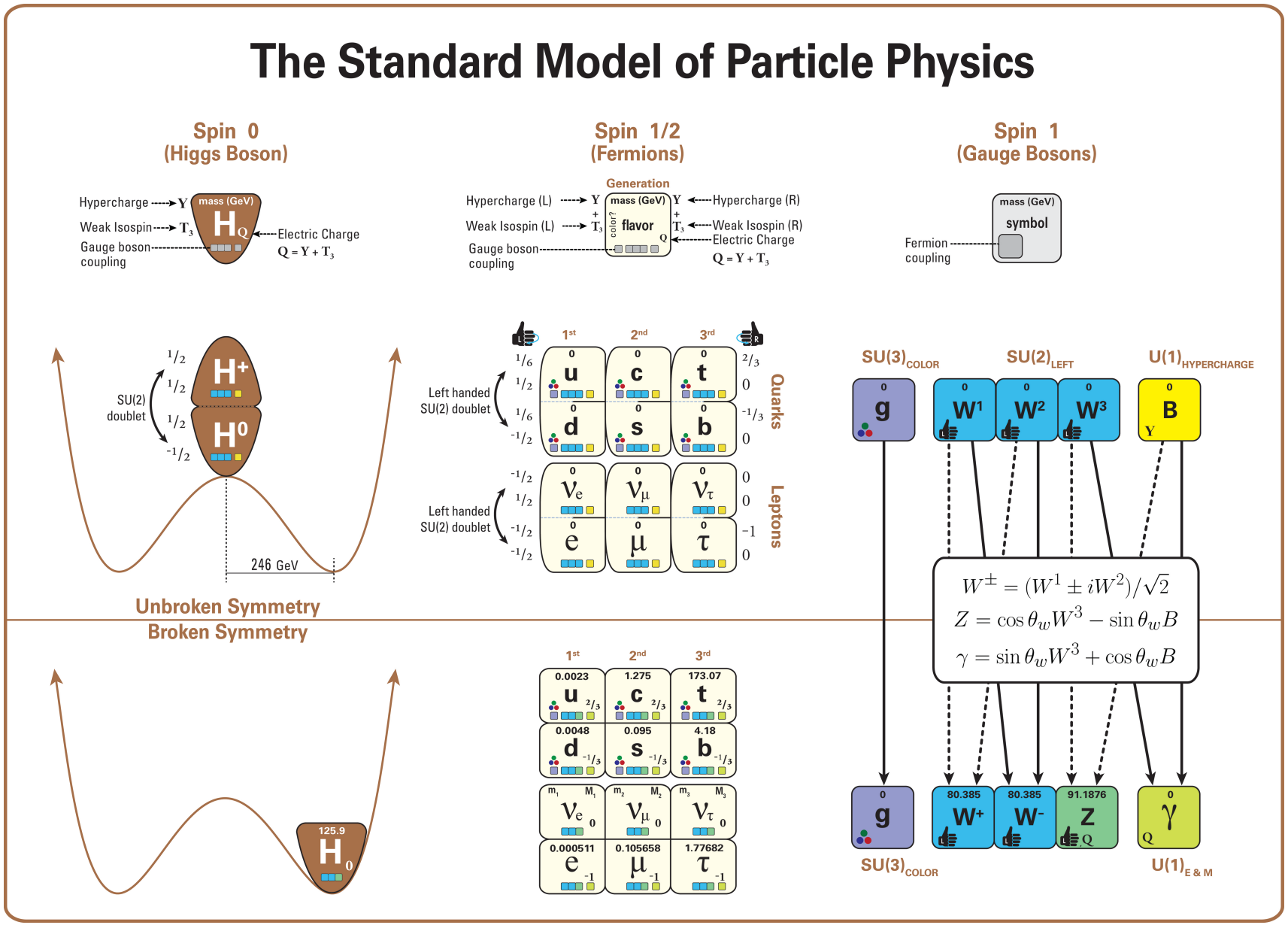
# Standard Model of Particle Physics

- Particle Physics
  - Also called high energy physics
  - Studies the nature of the particles and the fundamental interactions
- Standard Model
  - The Standard Model of particle physics describes current understanding of fundamental particles and their interactions

# Standard Model of Particle Physics

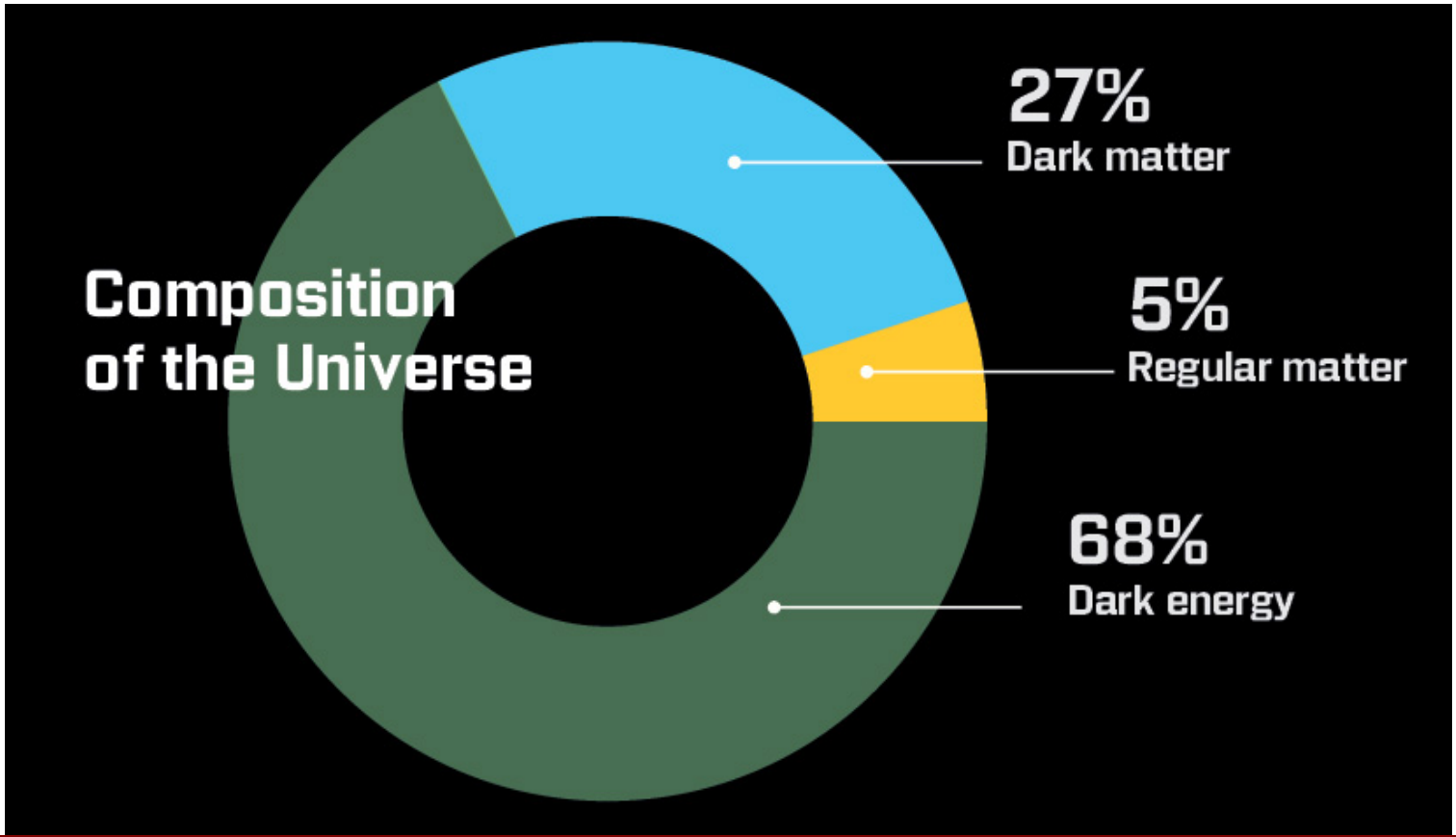
- 3 principles
  - Special Relativity
  - Quantum Mechanics
  - Gauge Invariance: $SU(3) \otimes SU(2) \otimes U(1)$
- 2 catogeries
  - Ferminos: spin 1/2 matter particles
  - Bosons: integer spin force carriers
- Higgs boson
  - Discovered in 2012
  - Gives mass to fundamental particles
  - Spontaneous symmetry breaking




The Standard Model of Particle Physics
Spin 0
(Higgs Boson)
Hypercharge
Weak Isospin
Gauge boson coupling
mass (GeV)
Electric Charge
Q = Y + T3
Spin 1/2
(Fermions)
Generation
Hypercharge (L)
Weak Isospin (L)
Hypercharge (R)
Weak Isospin (R)
color?
flavor
Spin 1
(Gauge Bosons)
Fermion coupling
symbol
SU(2) doublet
246 GeV
Unbroken Symmetry
Broken Symmetry
125.9
1st
2nd
3rd
Left handed SU(2) doublet
Quarks
Leptons
SU(3)COLOR
SU(2)LEFT
U(1)HYPERCHARGE
SU(3)COLOR
U(1)E & M
$W^{\pm} = (W^1 \pm iW^2)/\sqrt{2}$
$Z = \cos\theta_w W^3 - \sin\theta_w B$
$\gamma = \sin\theta_w W^3 + \cos\theta_w B$

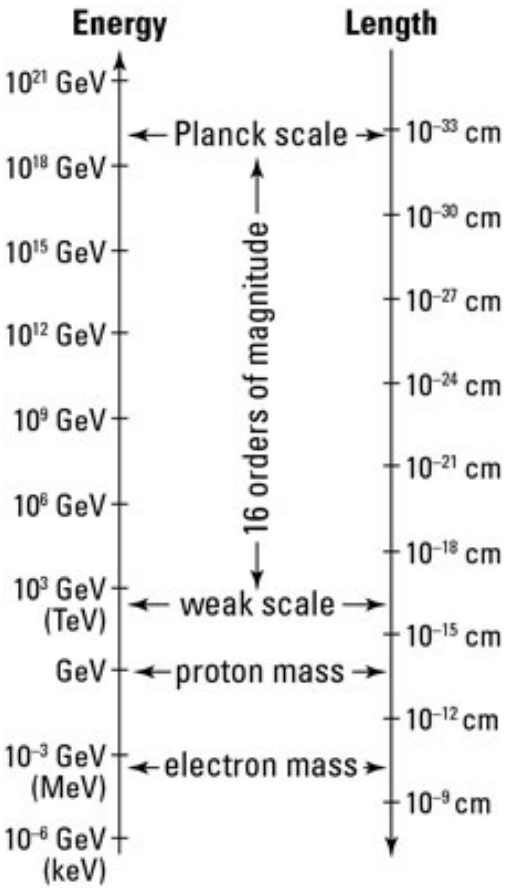
# Open questions of the SM

- The SM cannot explain: hierarchy problem, the Dark Matter & Dark Energy, Grand unification, etc..
- Example: Dark Matter & Dark Energy
  - Dark Matter doesn't absort, emit, and relect light
  - Dark Energy distributes throughout the universe
  - Cosmological data hints the presence of dark matter and dark energy

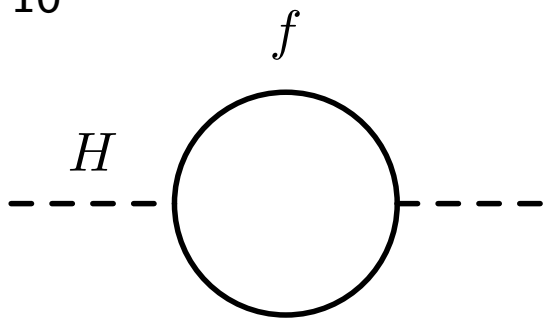


# Open questions of the SM

- The Standard Model is valid up to the Plank scale.
- The fundamental parameters of the Standard Model don't reveal anything about these scales of energy

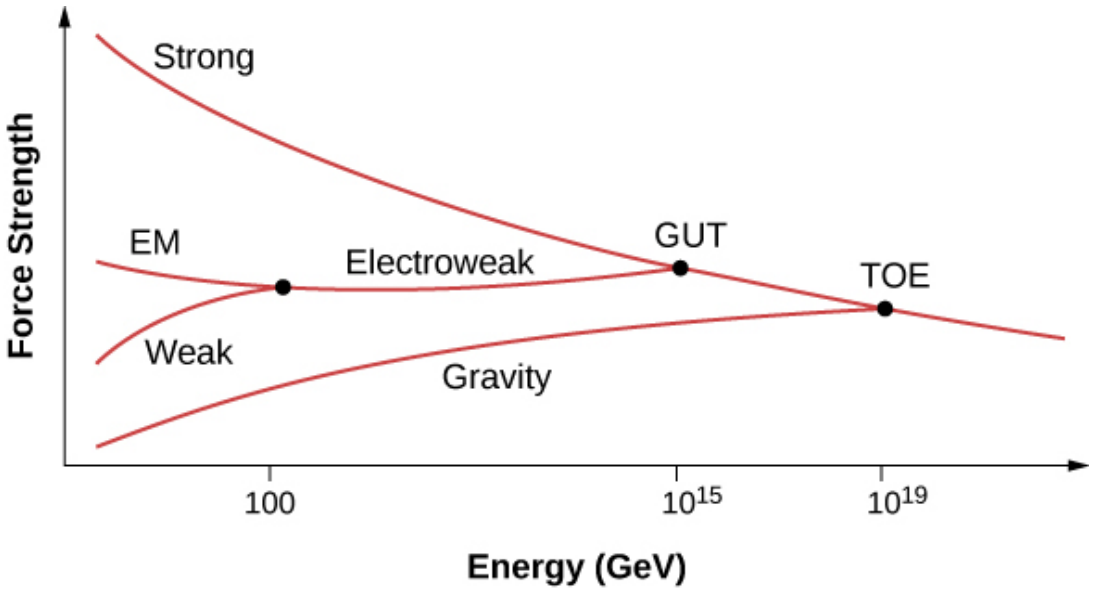



- Hierarchy problem:
  - Big gap in the energy scale
  - Weak scale and Plank scale: $\sim 10^{16}$
  - Weak force and gravational force: $\sim 10^{24}$
- Higgs mass: $m_H^2 = m_{bare}^2 + \delta m_H^2$
  - $m_H \sim 125$ GeV
  - $\delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi}\Lambda_{UV}^2$ is quadratically divergent
    At Plank scale $\Lambda_{UV}^2 \sim 10^{19}$ GeV
    $\Rightarrow \delta m_H^2 \sim 10^{38}$



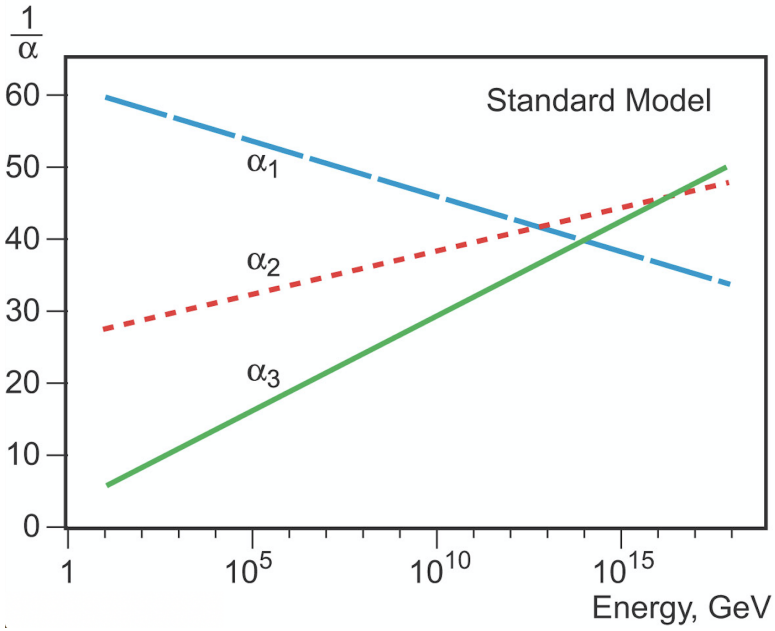
# Open questions of the SM

- Grand Unification Theory (GUT) expects:
  - Electromagnetic, weak, and strong forces unify at GUT scale ($\sim 10^{16}$ GeV)
  - Coupling constants $\alpha_1$, $\alpha_2$, and $\alpha_3$ converge

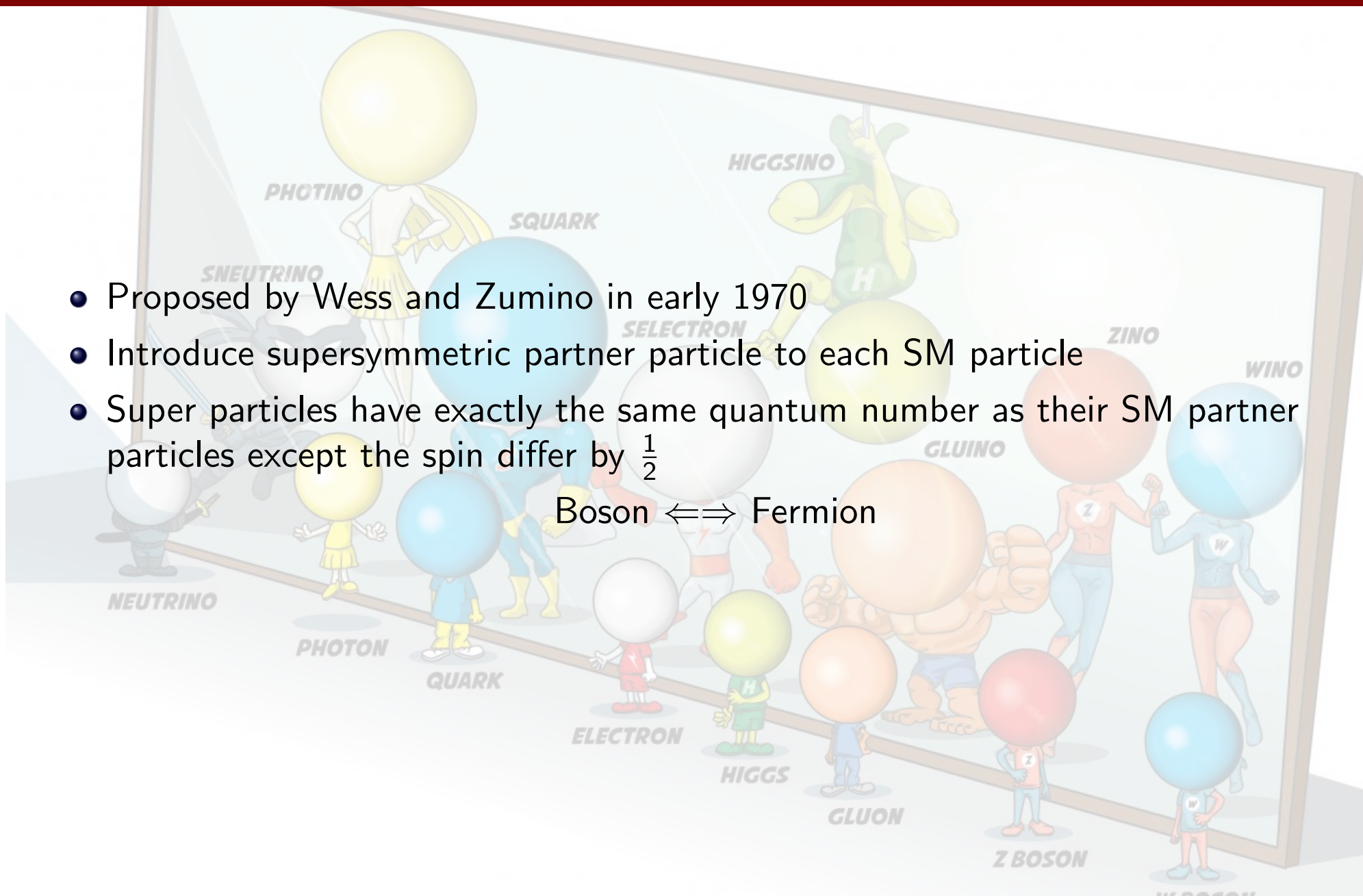



- Theory of Everything (TOE): combines GUT and gravity (if possible)

- Coupling constants do not converge in the SM



# Supersymmetry (SUSY)

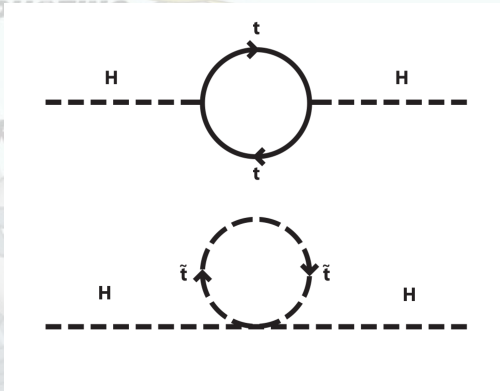



- Proposed by Wess and Zumino in early 1970
- Introduce supersymmetric partner particle to each SM particle
- Super particles have exactly the same quantum number as their SM partner particles except the spin differ by $\frac{1}{2}$

$$\text{Boson} \Longleftrightarrow \text{Fermion}$$

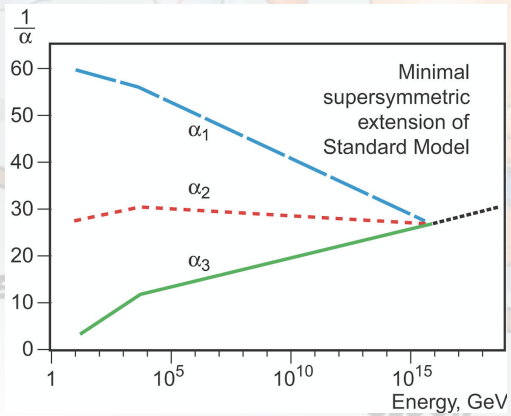
# Supersymmetry (SUSY)

- SUSY answers:
  - The hierarchy problem: opposite-sign loop corrections from SUSY particles




$$-\frac{|\lambda_f^2|}{8\pi^2}\Lambda_{UV}^2 + \frac{\lambda_S}{16\pi^2}\Lambda_{UV}^2 \times 2$$

  - The candidate of Dark Matter: Lightest SUSY Particle (LSP)
  - Coupling constants converge at GUT scale




  - and more

# Experimental Apparatus

# The Large Hadron Collider (LHC)

# ATLAS Detector

Section 3

# Conclusion

# Conclusion

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- and some bullets